MULTI-FREQUENCY TRANSMITTER USING PREDISTORTION AND A METHOD OF TRANSMITTING

The present invention relates to a transmitter and a method of transmitting and in particular, but not exclusively, for use in a telecommunications network.

In known wireless telecommunication networks 2 such as illustrated in Figure 1, the area covered by the network 2 is divided into a plurality of cells 4. Each cell 4 has associated therewith a base transceiver station 6. Each base station 6 is arranged to communicate with terminals located in the cell 8 associated with that base station 6. The terminals 8 may be mobile terminals which are arranged to move between the cells 4.

Each base station 6 in the GSM (Global System for Mobile communications) is arranged to transmit N frequencies out of M available frequencies C1....CM, as illustrated in Figure 2a. Each of the M frequencies is different and within the bandwidth allocated for signals transmitted by base stations. Each channel is divided into a plurality of sequential frames F one of which is shown in Figure 2b. Each frame F is divided into eight slots S0..S7. The GSM standard is a time/frequency division multiple access system (F/TDMA) and accordingly signals will be transmitted by the base station to different mobile stations in different time slots. In other words, the base station will transmit signals to different mobile stations in different time slots at the same frequency. N is usually much less than M.

With known base transceiver stations a separate transmitter circuit is generally provided for each different frequency. For illustrative purposes a known base transceiver station is shown in Figure 3. For the purpose of clarity only the transmit part 10 of the base station 12 is shown in Figure 3.

The transmit part 10 comprises N different transmit paths 14, one path being provided for each frequency. For clarity only the

arrangement of one path 14 is shown but it should be appreciated that each path 14 has the same structure. Each path 14 comprises a modulator 16 which modulates the signal to be transmitted. The modulated signal is output to an amplifier 18 which amplifies the modulated signal. The output of the amplifier 18 is then filtered by a bandpass filter 20 which removes or attenuates unwanted noise and other emissions such as spurious signals and intermodulation products.

The output of each transmit path 14 is connected to the input of a combiner 22 which combines the signals from each path 14 to provide a multicarrier signal. The output of the combiner 22 is connected to an antenna 24 which transmits the multicarrier signal containing each of the N different channels to the terminals in the cell served by the base station.

It is desirable to reduce the number of transmit paths to one as this would significantly reduce the costs involved. However, if a single amplifier were to be used with a number of channels at the same time, that amplifier would need to be very linear to prevent the leakage of power into adjacent channels. The leakage of power into adjacent channels is undesirable in that a reduction in system capacity and/or a reduction in signal quality results. Linear amplifiers are known but even these amplifiers are not linear when operated near the peak capacity of the amplifier.

Several methods have been proposed for ensuring that amplifiers are linear. It is known, for example, from International Patent Application No. WO 97/30521 to use predistortion in a transmitter to try to ensure linearity. Predistortion is used to try to ensure that a transmitter is linear. Amplifiers introduce non linearity. With predistortion, a signal is distorted prior to being input to the amplifier which causes the distortion. The predistortion applied is the inverse of the distortion caused by the amplifier. Thus the output of the amplifier will be linear with respect to the signal prior to the application of the

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5   predistortion and the passing of that signal through the amplifier. The transmitter illustrated in this document is of the type where a different transmit path is provided for each channel.

10   Reference is also made to the following papers: Linearization of Multi-Carrier Power Amplifiers by Johansson, Mattsson and Faulkner (IEEE 1993); Linearisation of RF multicarrier amplifiers using Cartesian Feedback by Johansson and Sundstrom (Electronics Letters 7 July 1994); and Linearization of Wideband RF Power
15   Amplifiers by Johansson and Faulkner. These documents disclose a transmitter which uses Cartesian feedback to correct for the non linearity of the amplifier. A signal from the output of the power amplifier is fedback and demodulated. The demodulated signal is subtracted from the input signals to provide an error
20   signal. The error signal is used to drive the modulator and the amplifier. The feedback is performed in the analogue domain. In these documents, a separate Cartesian feedback module is provided for each channel. It should be appreciated that Cartesian feedback is by its nature a narrow band linearization technique.
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It is an aim of embodiments of the present invention to provide a transmitter which can have only a single transmit path and which solves or at least mitigates the problems caused by a non linear amplifier.
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According to one aspect of the present invention, there is provided a multi frequency carrier transmitter comprising input means for receiving a plurality of different digital signals to be transmitted, said different signals to be transmitted on
35   different carrier frequencies; amplifier means for receiving a composite signal comprising said different signals at the respective carrier frequencies and amplifying said composite signal; and predistortion means for predistorting said plurality of digital signals prior to amplification of the composite signal
40   by said amplification means, said predistortion provided by said predistortion means being subsequently altered in dependence on

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the difference between said input signals and the output at said amplifier means.

Accordingly, embodiments of the present invention provide a multi carrier transmitter which is able to deal with the problems of nonlinearity by using predistortion. The predistortion can be implemented more simply than the feedback method discussed in the prior art.

The input means are preferably arranged to separately receive each of the different signals. Combiner means are preferably provided between the input means and the amplifier means for combining said plurality of different signals to provide a composite signal. This may be the composite signal input to the amplifier means or may be a composite signal at a lower, intermediate frequency. In the latter case, that composite signal at a lower frequency would be upconverted to provide the composite signal input to the amplifier means.

Preferably the predistortion means are arranged to individually predistort each of the different signals before the plurality of different signals are combined by said combiner. This has the advantage that it is easy to ensure that different predistortion coefficients appropriate for the respective carrier frequency are applied to each of the signals which will be at the respective different carrier frequencies.

Alternatively, the predistortion means may be arranged to predistort the composite signal after the plurality of signals have been combined by the combiner.

A feedback path may be arranged between the amplifying means and the predistorting means. Preferably, the predistorting means is arranged to compare the output from the amplifying means from the feedback path with the signals received by the receiving means and to provide, if necessary, at least one new predistortion value to be applied to at least one subsequent signal received

by the receiving means. In this way, the predistorting means can adapt to changes in the operating conditions of the amplifier means.

Preferably, means are provided in the feedback path for separating the output of the amplifying means into a plurality of different signals. The predistorting means is preferably arranged to compare each of the separated signals with the corresponding signals received from the input means and to determine if the at least one predistortion value needs to be altered.

Alternatively, the predistorting means is arranged to compare the composite signal from the amplifying means with a plurality of different signals to provide, if necessary, the at least one new predistortion value.

The predistortion means are preferably arranged to provide a plurality of predistortion coefficients, at least one predistortion coefficient being provided for each multi carrier frequency. Different predistortion coefficients are preferably provided for each multi carrier frequency regardless of the way in which the predistortion is achieved in practice.

Preferably, the predistortion coefficients for each multicarrier frequency take into account characteristics of other of the said multicarrier frequencies. Those characteristics can include one or more of the following: frequency; and distortion caused by the amplifier means.

The amplifier means is preferably a nonlinear amplifier. The predistortion means is preferably arranged to compensate for the nonlinearity of the phase and/or amplitude of the output of the amplifier.

A digital to analogue converter may be provided for converting the plurality of signals to analogue form before said signals are

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5   amplified by said amplifier means.

The transmitter is preferably incorporated in a base station or
alternatively in a mobile station.

10   According to a second aspect of the present invention, there is
provided a multi carrier frequency transmission method comprising
the steps of receiving a plurality of different digital signals
to be transmitted, said different signals to be transmitted on
different carrier frequencies; combining said plurality of
15   different signals to provide a composite signal comprising the
different signals at the respective carrier frequencies; and
amplifying said composite signal, wherein the method further
comprises the steps of: predistorting the plurality of different
digital signals prior to amplification of the composite signal
20   by the amplification means; and altering the predistortion
applied to subsequent signals in dependence on the difference
between said different signals and the amplified signal.

For a better understanding of the present invention and as to how
25   the same may be carried into effect, reference will now be made
by way of example to the accompanying drawings in which:
Figure 1 shows a typical wireless telecommunications network;
Figure 2a shows the M available frequencies for transmitting to
terminals by base stations;
30   Figure 2b shows the structure of a frame;
Figure 3 shows the transmit part of a known base station;
Figure 4 shows the transmit part of a first base station
embodying the present invention;
Figure 5 shows the transmit part of a second base station
35   embodying the present invention;
Figure 6 shows the transmit part of a third base station
embodying the present invention;
Figure 7 shows a predistorter, which can be used in the first and
second embodiments, in more detail;
40   Figure 8 shows a second predistorter, which can be used in the
first and second embodiments, in more detail;

Figure 9 shows a third predistorter which can be used in the
third embodiments, in more detail; and
Figure 10 shows a channelizer.

Reference will now be made to Figure 4 which shows a first
embodiment of the present invention. In particular, the transmit
part 102 of the base station 100 is shown. The base station 100
is in a cellular system of the type shown in Figure 1.

The transmit part 102 of the base station 100 comprises N channel
encoders 104 where N is the number of different frequencies on
which the base station 100 will transmit signals. Each channel
encoder 104 receives the data to be transmitted on the particular
frequency associated with the given channel encoder 104. The data
is placed in a suitable form for transmission. This may include
digitising the data, encoding the data, interleaving the data
and/or any other step required to be carried out. As mentioned
hereinbefore, each channel is on a different frequency after the
modulator. The signals output by the channel encoders 104 are in
digital form and are at a baseband frequency. Coding,
interleaving etc is performed on the digital baseband signals.

The output of each channel encoder 104 is input to a respective
digital modulator 106. Each digital modulator 106 also receives
two outputs from the adaptive predistorter 108. The first output
from the predistorter 108 provides one or more amplitude
coefficients which are used to predistort the signal which is
output by the digital modulator to compensate for the non
linearity of an amplifier 122 with respect to amplitude. The
second output from the predistorter 108 provides one or more
phase coefficients which are used to predistort the signal which
is output by the modulator 106 to compensate for phase distortion
provided by the amplifier 122. The amplifier 122 will be
described in more detail hereinafter.

The digital modulators 106 are arranged to modulate the output
of the respective channel encoders 104 according to the
modulation method use by the telecommunications system of which

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the base station 100 forms a part. In the case of the GSM
standard the modulators 106 will perform Gaussian minimum shift
keying (GMSK). In general terms the modulators 106 take the
baseband input from the respective channel encoder 104, pass that
input through a shaping filter and mix the signal with a carrier
signal at an intermediate frequency which is higher than the
baseband frequency but less than the frequency at which the
signals are transmitted to thereby provide a modulated output.
The predistortion to compensate for the phase and amplitude
distortion introduced by the amplifier 122 can take place at the
same time. The predistortion can be performed during or more
preferably after the modulation has been carried out by the
modulator 106.

The output of each of the digital modulators 106 are input to a
signal combiner 11 and to the adaptive predistortor 108. The
combiner 110 combines the outputs of all of the modulators 106
to provide a single output. That output contains the signals for
each of the frequencies. It should be appreciated that the output
of the combiner 110 provides a single stream of digital words
which represent the amplitude of the composite signal at each
sampling instant. The output of the combiner 110 is input to a
digital to analogue converter 112 which converts the digital
wideband signal output by the combiner to an analogue signal.

The output of the digital to analogue converter 112 is input to
a first bandpass filter 114 which removes signal components
generated by the digital to analogue converter 112 which are
outside the intermediate frequency band. The output of the first
bandpass filter 114 is input to a first mixer 116. The first
mixer 116 also receives an input from a first local oscillator
118. The output of the first bandpass filter 114 is thus mixed
by the first mixer 116 with the output of the first local
oscillator 118 to provide an output containing the N signals,
each of which is at the radio frequency at which that signal is
to be transmitted. Each of the N signals will thus be at a
different radio frequency. The frequency of the first local

oscillator 118 is thus selected to allow the intermediate frequency signals to be upconverted to the required radio frequencies by the first mixer 116.

The output of the first mixer 116 is input to a second bandpass filter 120 which removes any signal components introduced by the first mixer 116 which are outside the radio frequency band of the signals to be transmitted.

The output of the second bandpass filter 120 is input to the power amplifier 122 which amplifies the received input. The output of the amplifier 122 is input to a third bandpass filter 124 which is arranged to filter out any signal components introduced by the amplifier 122 which fall outside the radio frequency band of the signals to be transmitted. The output of the third bandpass filter 124 is passed to an antenna 126 which transmits the signals to the terminals in the cell associated with the base station.

Between the amplifier 122 and the third bandpass filter 124, there is arranged a coupler 128 which is arranged to sample a small part of the signals which are transmitted. In other words, the coupler 128 allows a small proportion of the signals to be transmitted to be sampled. The coupler 128 outputs an analogue sample of the output signal which is typically below the power of the input to the third bandpass filter 124.

The output of the coupler 128 is input to a second mixer 132 which receives a signal from a second local oscillator 134. The signals which are received from the coupler 128 are in the radio frequency band. The signal from the second local oscillator 134 is at a frequency such that when the signals from the coupler 128 are mixed with signal from the local oscillator 134, the output of the second mixer 132 consists of the signals which were transmitted but at the intermediate frequencies. The intermediate frequencies output by the second mixer 132 may but not necessarily be the same as the intermediate frequencies input to

5   the first mixer 116. Accordingly, the frequency of the signals
       provided by the first and second oscillators 118 and 134 may be
       the same. In that case, a single oscillator may be provided.

       The output of the second mixer 132 is input to a fourth bandpass
10   filter 136 which filters out any signal components introduced by
       the second mixer 132 which are outside the intermediate frequency
       band. The output of the fourth bandpass filter 136 is input to
       an analogue to digital converter 138 which is arranged to convert
       the analogue signals to digital form.

15   The digital signals are output by the analogue to digital
       converter 138 to a channelizer 140. The channelizer 140 divides
       the signals into the N different frequencies corresponding to the
       frequencies on which those signals were transmitted. The
20   channelizer 140 is able to distinguish the N signals as they are
       all at different frequencies. The channelizer 140 provides N
       outputs, one for each of the frequencies. Each of the N outputs
       provided by the channelizer 140 are input to the adaptive
       predistorter 108. The channelizer 140 can be provided in any
25   suitable way including a bank of digital downconverters and fast
       fourier transform circuitry.

       The adaptive predistorter 108 thus receives for each channel a
       version of the signal before it passes through the combiner 110
30   and subsequent elements of transmit part 102 of the base station
       100 (from the respective digital modulator) and a version of the
       signal after it has passed through the transmit part 102 (from
       the channelizer 140). The predistorter 108 thus compares like
       versions of the same signal eg, both signals will be modulated
35   at the same frequencies. The adaptive predistorter 108 is
       arranged to compare these signals. If the coefficients which the
       predistorter 108 outputs to the given digital modulator are good
       then the signal which is transmitted should be the same as the
       respective signal which is input to the combiner 110. Ideally the
40   only differences should be in scale of the signals. If the
       signals differ, the predistorter 108 arranged to calculate new

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predistortion coefficients which take into account the results
of the comparison.

Thus, the predistorter 108 compares for each frequency the signal
which was transmitted with the signal output by the respective
digital modulator 106. For each frequency it is determined if the
current predistortion coefficients are acceptable and if not
calculates new coefficients to be used for that channel.
Predistortion is thus performed individually for each frequency
prior to signal combining. The predistortion coefficients for
each frequency are determined based on feedback from the
corresponding frequency as transmitted. The predistortion
coefficients are arranged to compensate for non-linearity with
respect to amplitude and also phase distortion. The phase and
amplitude of the signals of the digital modulators 106 are
altered in accordance with these coefficients. How these
coefficients are used will depend on the modulation method. In
the simplest cases, the coefficients could be added to the signal
or used as multipliers.

A microcontroller 142 is provided which provides control signals
to the predistorter 108, the combiner 110, the channelizer 140
and the first and second local oscillators 118 and 134. The
microcontroller 142 is arranged to control the frequency of the
signals generated by the oscillators 118 and 134.

The embodiment of Figure 4 has the advantage that each of the
individual channels are input to the adaptive predistorter on the
input side and the individual channels are received from a
channeliser on the output side. Therefore, the predistortion
coefficients that are calculated by the adaptive predistorter are
based on all of the carriers. This allows optimal performance to
be obtained since all the information is available.

The combiner 110 requires information on the frequency if an
inverse fast fourier transform combining technique is required.
The algorithm performed by the adaptive predistorter 108 may

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5   also, as discussed hereinbefore utilise frequency information
    when calculating the predistortion coefficients.

    Reference will now be made to Figure 7 which shows a first
    predistorter which can be used in the arrangement of Figure 4.
10 The predistortor 108a comprises n subtracters 202 each of which
    receives a respective one of the outputs from the digital
    modulators 106. Each subtracter also receives a input from the
    channeliser 140. Each subtracter 202 receives the output from the
    modulator 106 corresponding to a given user and the output from
15 the channeliser 140 which also corresponds to that user. The
    subtracter 202 subtracts one of the outputs from the other to
    thus determine the difference between those signals. The output
    of each subtracter 202 thus constitutes a difference signal which
    is input to an adaption algorithm block 204 which on the basis
20 of the input received from the subtractors 202 calculates, if
    necessary, new amplitude and phase predistortion coefficients.
    These amplitude and phase coefficients are output to a look-up
    table 200 where they are stored. The values from the look-up
    table 200 are supplied, as shown in Figure 4, to the respective
25 digital modulators 106. The adaption algorithm block 204 may also
    receive an input from the microcontroller 142 which provides
    information as to the frequency of the signals. This information
    can be used by the adaption algorithm block 204 to calculate the
    amplitude and phase predistortion coefficients.

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    Reference will now be made to Figure 5 which shows a second
    embodiment of the present invention. The embodiment shown in
    Figure 5 is similar to the embodiment shown in Figure 4 and
    accordingly only the differences between the first and second
35 embodiments will be described.

    The adaptive predistorter 108 does not, as in the first
    embodiment, have outputs connected to the digital modulators 106.
    The output of the combiner 110 is connected to the input of the
40 predistorter 108. The output of the predistorter 108 is connected
    to the input of the digital to analogue convertor. The

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5   predistorter 108 thus predistorts the multicarrier output of the
       combiner 110 and outputs a predistorted multicarrier signal. The
       feedback path is the same in the first and second embodiments and
       accordingly the predistorter 108 operates in a similar manner to
       that shown in the first embodiment. However, phase correction is
10   not applied and the amplitude correction is the same for all
       frequencies. This solution is simple but may not provide the
       required performance in all cases.

       Reference will now be made to Figure 8 which shows a second
15   predistorter 108b which can be used in the second embodiment
       shown in Figure 5. This second predistorter 108 comprises n
       subtractors 208 each of which receives an output from a
       respective one of the digital modulators. Each subtracter 208
       also receives a corresponding input from the channelizer 140 as
20   in the first embodiment. Each subtracter 208 thus receives two
       modulated signals. The two signals received by each subtracter
       208 are subtracted one from the other to generate a difference
       signal. This output difference signal is input to the adaption
       algorithm block 204 which is the same as discussed in relation
25   to the first predistorter of Figure 7. As with the first
       predistorter of Figure 7, the adaption algorithm block 204 also
       receives an input from the microcontroller 142 with information
       concerning the frequency. The adaption algorithm block 204
       provides amplitude coefficients on its output which are output
30   to the look-up table 200. Unlike the embodiment shown in Figure
       7, the look-up table receives the multicarrier signal from the
       combiner 110 which defines an address in the look-up table.
       Accordingly, the multicarrier signal is modified in accordance
       with the amplitude values from the look-up table and output to
35   the digital to analogue convertor 112.

       Reference is now made to Figure 10 which shows a possible
       construction of the channeliser 140. The channeliser comprises
       n blocks 220, with one block provided for each frequency. Each
40   block of the channeliser 220 comprises an input for receiving the
       output of the analogue to digital converter 138 and a frequency

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control signal from the microcontroller 142. The output from the
analogue to digital converter 138 is input to first and second
multipliers 222 and 224. The first multiplier 222 produces the
I or in-band, component of the input signal whilst the second
multiplier 224 produces the Q, or quadrature-phase component of
the input signal. Each of the multipliers 222 and 224 receives
a frequency from the numerically controlled oscillator 226. The
frequency of the oscillator 226 is controlled by the frequency
control input. The output of the oscillator 226 is connected
directly to one of the multipliers 222 whilst the output for the
second multipliers 224 is connected to a phase shifter 228 which
shifts the phase of the output signal from the oscillator 226 by
90°. The phase shifted output signal of the oscillator 226 is
input to the second multipliers 224.

The output of each of the first and second multipliers 222 and
224 are connected to filters 230 and 232 which are arranged to
filter out signal components introduced by the respective
multipliers as well as other carriers within the multicarrier
signal.

Each element 220 thus provides two outputs, one for the I
component and one for the Q component for each frequency.

The frequency information provided by the microcontroller 142 is
used by the predistorter 108 in the third embodiment to
reconstruct the composite signal using any appropriate method.
The methods require frequency information. One example is the
inverse fast fourier transform technique which creates a spectral
representation of the signal sampled in the time domain.

Reference will now be made to Figure 6 which shows a third
embodiment of the present invention. As with the second
embodiment of the present invention, only the differences between
the first and third embodiments will be discussed.

The channelizer 140 of Figure 4 has been omitted from the

5   embodiment of Figure 6. The output of the analogue to digital
        converter 138 is thus connected directly to the input of the
        predistorter 108. As information is only available on the
        composite signal, the predistorter is arranged to create a
        reference.

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        Reference will now be made to Figure 9 which shows a third
        embodiment of a predistorter which can be used in the embodiment
        of Figure 6. The third predistorter 108c receives the outputs
        from the digital modulators 106. The output of each of the
15   digital modulators 106 is input to a combiner 212 which combines
        the outputs of the modulators 200 to provide a single signal
        which is input to a single subtracter 214. The single subtracter
        214 also receives the output of the analogue to digital converter
        138. The single subtracter 214 provides a difference signal as
20   a result of subtracting one of the outputs from the combiner 212
        and the analogue to digital converter 138 from the other. This
        difference signal is input to an adaption algorithm block 216
        which calculates, if necessary new amplitude and phase distortion
        coefficients. As with the first two predistorters, the adaption
25   algorithm block 216 receives an input from the microcontroller
        146 with information concerning the frequency. This information
        is also input to the combiner 212. The new values are stored in
        the look-up table 200.

30   In the previously described embodiments, the output from the
        digital modulators are input to the adaptive predistorter. In an
        alternative embodiment, the output of the channel encoders may
        be output to the adaptive predistorter instead. In those
        circumstances, the channeliser may need also to demodulate the
35   signals so that the adaptive predistortor compares like with
        like.

        The embodiments which calculate the predistortion coefficients
        for each carrier can be modified so that the frequency,
40   distortion etc on the other carriers are taken into
        consideration.

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In the embodiments where the composite signal is predistorted,
the combiner output consists of amplitude words, the correction
occurring by adjusting the magnitude of the words. Nonlinearities
in the amplifier output could be compensated by correcting the
magnitude of the combiner output words with an inverse function.
The correction may thus be dependent on the particular combiner
output. This might occur by indexing a look-up table with the
combiner output word and outputting the respective contents to
the digital to analogue converter.

In the embodiments of the present invention described
hereinbefore, only one set of intermediate frequencies is used.
However in alternate embodiments of the present invention, there
may be a further stage where the frequencies of the signals at
a first set of intermediate frequencies may be upconverted to a
second set of intermediate frequencies which are greater than the
first set of intermediate frequencies but less than the radio
frequency.

Whilst the embodiment of the present invention has been described
in the context of the GSM standard it should be appreciated that
embodiments of the present invention are applicable to any other
TDMA system, any system using spread spectrum techniques such as
code division multiple access (CDMA), frequency division multiple
access (FDMA) or hybrids of any of these methods. For example GSM
is an FDMA/TDMA hybrid.

It should be appreciated that although the preferred embodiment
of the present invention has been described in the context of a
base transceiver station, embodiments of the present invention
are also applicable to mobile stations and terminals which are
arranged to communicate with the base station. Embodiments of the
present invention can be used with any suitable transmitter which
is sending signals at more than one frequency at the same time
in both wireless and wired environments.